

2.0 RESEARCH QUESTIONS

2.1 Introduction to the Research Plan

In 1997, the South Florida Water Management District undertook an Estero Bay and Watershed Management and Improvement Plan, a multi-year project. The District's prime consultant, is charged with conducting an Estero Bay Assessment and an Estero Watershed Assessment. The watershed assessment will develop land and water management strategies to achieve water quality and quantity objectives for the Bay. Major assessment activities include physical descriptions of major features and current management practices, identification of water quality trends, ranking of potential pollution problem areas, and compilation of input data for a watershed model to evaluate management scenarios. A subsequent assessment phase utilizes modeling for scenario evaluation.

The Estero Bay Assessment will define water quality and water quantity objectives or pollution load reduction goals for the Bay and develop tools to evaluate the effects of watershed management techniques on the Bay. The Estero Bay Assessment involves the application of a logical protocol for designing study and management plans, to identify the types of pollutants and their impacts on estuarine environments. The first and present phase of the assessment will result in an Estero Bay Research Plan, based on management goals for the estuary. A subsequent assessment phase implements the research plan.

The Estero Bay Research Plan follows a method developed by Mote Marine Laboratory for the South Florida Water Management District's study of the St. Lucie River and estuary. The general method is described in Hayward *et al.* 1991a and 1991b, Estevez *et al.* 1991, and Estevez and Hayward 1992. Its application to the St. Lucie River system is described in Dixon *et al.* 1993, Dixon and Lowery 1993, Dixon *et al.* 1994, and Dixon and Hayward 1995.

First, goals are established for the Bay. Next, research questions appropriate to each goal are identified. Finally, specific analytical methodologies are defined to answer each research question. Taken as a whole, these tasks will comprise the Estero Bay Research Plan.

In Chapter 1, goals were identified through an analysis of existing laws, rules, policies, and other statements of social expectations for the Bay ("authorities"). These same sources provided insight to the valued ecosystem components of the Bay. Primary goals were developed around each major ecosystem component, and were written to meet criteria of meaningfulness, verifiability, and practicality. Secondary goals were identified around stressors known or suspected to play a significant role in regulating the condition of valued ecosystem components. Where needed, tertiary

goals were identified in order to complete a causal link between valued ecosystem components, and management actions.

2.1.1 Goals from Chapter 1 Are:

1.0. Restore the area, location, species composition, and condition of submerged aquatic vegetation (SAV-- sea grasses, rooted macrophytic algae) to pre-development conditions.

- 1.1. Bring proximate stressors of SAV (light, turbidity, salinity, exposure, biotic regulators, etc.) into ranges suitable for natural recolonization within areas of SAV extirpation.

- 1.1.1. Modify quantity and quality of freshwater inflows (surface water, ground water) as needed to relieve proximate stressors, within the context of natural geologic conditions in the Bay.

2.0. Create conditions of water quality necessary to increase the area of Estero Bay designated as Class II (shellfish propagation or harvesting) waters of the State, and permit some area of the Bay to be classified "approved" for shellfish consumption.

- 2.1. Bring proximate stressors of shellfish productivity and sanitation (pathogens, turbidity, salinity, exposure, biotic regulators, etc.) into ranges suitable for shellfish propagation and harvesting.

- 2.1.1. Modify quantity and quality of freshwater inflows (surface water, ground water) as needed to relieve proximate stressors, within the context of natural geologic conditions in the Bay.

3.0. Register the location, size, and duration of oligohaline habitat (salinity less than 10 parts per thousand) to pre-development conditions.

- 3.1. Modify quantity and timing of freshwater inflows (surface water, ground water) as needed, within the context of natural geologic conditions in the Bay.

Each of the three primary goals is meaningful in the context of Bay management. Each is verifiable through empirical measurement, and each is practical (achievable with existing technology). Primary goals address primary and secondary producers at the species, community, and habitat levels of biological organization. Each is traceable through intermediate goals to major management issues of freshwater inflow, and water quality.

The goals are used in this project task to develop empirical questions of two forms: one form seeks to establish status and trends of the estuary, and the other form asks questions regarding controlling processes. Such questions will guide the definition of analytical methods which, when implemented in the second phase of the Estero Bay Assessment, are expected to generate information useful in the definition of water quality and water quantity objectives or pollution load reduction goals for the Bay.

2.2 Research Questions and Their Rationale

2.2.1 On the Nature of Research Questions

The Estero Bay plan intends that recommended research be basic in nature, i.e., result in new discoveries about the structure and function of the Bay, but that such discoveries also be applicable to contemporary issues of Bay management. Properly crafted, the research plan will identify those particular investigations having, as a whole, a high probability of being useful to resource managers. Research questions are heuristic tools that communicate which aspects of Bay structure and function will be investigated, and which will not. The questions allow investigators to infer types of requisite methods and data, and to continually check that methods and data are responsive to research goals. Research questions are not hypotheses. Hypotheses specify an expected and falsifiable outcome of a test, and hypotheses are informed by prior experience and observation. Research questions are more open-ended than hypotheses.

2.2.2 On Segmentation

Segmentation, or the geographic partitioning of a study area, is a useful tool in the design of research and monitoring programs. Segmentation recognizes variations and gradients that occur naturally in a coastal landscape. It simplifies and makes explicit assumptions about stratification in the design of statistical analyses, and allows for the equitable distribution of effort to be tested among and between segments. The process also allows for some geographic areas to receive unique monitoring or research efforts.

Depending upon the end-use of the segments, geographic areas may be defined on the basis of a few or many distinguishing features. Florida Bay's separate carbonate and oolite sediment regions

illustrate a single geological basis for geographic segmentation. In Tampa Bay, segments have been based on multiple features of depth, circulation, and distance to the Gulf of Mexico. Segmentation of Sarasota Bay, for the National Estuary Program, employed the additional consideration of "problemsheds," or foci of human activity deserving special monitoring attention.

Segmentation relies heavily on existing information to match bay regions to monitoring and research effort, although it is possible to conduct scoping studies or reconnaissance surveys upon which a preliminary segmentation system can be based. Elements of surveys made for such purposes depend largely on the questions upon which new monitoring or research will be based: a detailed study of sediment contaminants, for example, would seek to map Bay depths, granulometry, and circulation patterns as input to a segmentation scheme, but data on living resources might not be initially as important.

As outlined in Chapter 1, considerable data exist for the Estero Bay area. Data of the types and kinds needed for segmentation are fewer because historic effort has not been uniformly dispersed across the Bay; changes in historic conditions are believed to have occurred, but are not completely documented as yet, and even the boundaries of Estero Bay's watershed are changing as new data are analyzed.

Finally, segmentation is employed most effectively after specific questions have been developed to guide monitoring or research programs, which is the purpose of the present chapter. Consequently, segmentation of Estero Bay will be deferred to Chapter 3, Research Methods. Readers of this chapter should, however, appreciate that research questions described in following sections will distinguish fresh waters from Bay waters. As used below, fresh waters are meant primarily to include the major inflows such as Ten-Mile Canal, Estero and Imperial Rivers, as well as other named and unnamed surface waters tributary to the Bay. Bay waters are meant primarily to include tidal waters up to the mouths of these waterways.

Chapter 3 will expand upon the use of Estero Bay's geographic segmentation as a research method, and Chapter 4, which details specific research investigations, will begin with a description of rapid survey efforts needed to execute the recommended studies.

2.2.3 Two Types of Research Questions

Two kinds of questions are posed, as noted previously. The first kind seeks to learn the status of a given resource, or the spatial and temporal characteristics of a controlling factor. The first kind of question also seeks to determine trends, i.e., whether changes in VEC or controlling factors have occurred through time. In the following list, questions of the first kind are numbered in a "STQ" or *Status and Trends Question* series.

The second type of question seeks to learn the nature of causal relationships between VEC and controlling factors, or among controlling factors. These are numbered in a “CPQ” or *Controlling Processes Question* series. In both cases, the questions follow individual goal statements.

2.2.4 Status and Trend Questions

1.0. **Restore the area, location, species composition, and condition of submerged aquatic vegetation (SAV-- sea grasses, rooted macrophytic algae) to pre-development conditions.**

STQ. 1. What was the pre-development area, location, species composition, and condition of submerged aquatic vegetation?

STQ. 2. What changes in SAV area, location, species composition, and condition have occurred from pre-development to modern times?

1.1. **Bring proximate stressors of SAV (light, turbidity, salinity, exposure, biotic regulators, etc.) into ranges suitable for natural recolonization within areas of SAV extirpation.**

STQ. 3. What are the present-day ranges of light, turbidity, chlorophyll, color, nutrients, salinity, and exposure values in the Bay?

STQ. 4. What are the distributions and statistical properties of these stressor values?

STQ. 5. How are ranges, distributions, and statistical properties of stressors dispersed spatially within the Bay?

STQ. 6. How have descriptors of present-day stressors changed over the period of available data?

1.1.1. **Modify quantity and quality of freshwater inflows (surface water, ground water) as needed to relieve proximate stressors, within the context of natural geologic conditions in the Bay.**

STQ. 7. What is the quantity of gaged and ungaged surface water flow, and of ungaged groundwater flow, to the Bay?

STQ. 8. What are the distributions and statistical properties of these inflow values?

STQ. 9. How are surface and groundwater inflows to the Bay spatially dispersed?

STQ. 10. How have descriptors of present-day surface and groundwater inflows changed over the period of available data?

STQ. 11. What are the concentrations of mineral turbidity, organic turbidity, nutrients, color, and chlorophyll in fresh waters flowing to the Bay?

- STQ. 12. What are the distributions and statistical properties of these constituent concentration values?
- STQ. 13. How are distributions and statistical properties of constituent concentrations dispersed spatially within the Bay?
- STQ. 14. How have descriptors of present-day constituent concentrations changed over the period of available data?
- STQ. 15. How thick are Bay sediments and what is the spatial dispersion of sediments on the Bay bottom?
- STQ. 16. What changes in sediment type, thickness, or spatial dispersion have occurred in recent times?

2.0. Create conditions of water quality necessary to increase the area of Estero Bay designated as Class II (shellfish propagation or harvesting) waters of the State, and permit some area of the Bay to be classified "approved" for shellfish consumption.

- STQ. 17. What is the present-day pattern of molluscan shellfish diversity and abundance in the Bay?
- STQ. 18. What was the pre-development pattern of molluscan shellfish diversity and abundance in the Bay?

2.1. Bring proximate stressors of shellfish productivity and sanitation (pathogens, turbidity, salinity, exposure, biotic regulators, etc.) into ranges suitable for shellfish propagation and harvesting.

- STQ. 19. What are the present-day ranges of pathogens, turbidity, salinity, chlorophyll, particulate organic matter, and exposure values in the Bay?
- STQ. 20. What are the distributions and statistical properties of these stressor values?
- STQ. 21. How are ranges, distributions, and statistical properties of stressors dispersed spatially within the Bay?
- STQ. 22. How have descriptors of present-day stressors changed over the period of available data?

2.1.1. Modify quantity and quality of freshwater inflows (surface water, ground water) as needed to relieve proximate stressors, within the context of natural geologic conditions in the Bay.

- STQ. 23. What is the quantity of gaged and ungaged surface water flow, and of ungaged groundwater flow, to the Bay?
- STQ. 24. What are the distributions and statistical properties of these inflow values?

- STQ. 25. How are surface and groundwater inflows to the Bay spatially dispersed?
- STQ. 26. How have descriptors of present-day surface and groundwater inflows changed over the period of available data?
- STQ. 27. What are the concentrations of particulate organic matter, chlorophyll, and pathogens in freshwaters flowing to the Bay?
- STQ. 28. What are the distributions and statistical properties of these constituent concentration values?
- STQ. 29. How are distributions and statistical properties of constituent concentrations dispersed spatially within the Bay.
- STQ. 30. How have descriptors of present-day constituent concentrations changed over the period of available data?

3.0. Register the location, size, and duration of oligohaline habitat (salinity less than 10 parts per thousand) to pre-development conditions.

- STQ. 31. What was the pre-development area, location, species and community composition, and condition of oligohaline habitat?
- STQ. 32. What changes in oligohaline habitat area, location, and size have occurred from pre-development to modern times?

3.1. Modify quantity and timing of freshwater inflows (surface water, ground water) as needed, within the context of natural geologic conditions in the Bay.

- STQ. 33. What is the quantity of gaged and ungaged surface water flow, and of ungaged groundwater flow, to the Bay?
- STQ. 34. What are the distributions and statistical properties of these inflow values?
- STQ. 35. How are surface and groundwater inflows to the Bay spatially dispersed?
- STQ. 36. What physical changes to the bathymetry of the Bay, its tributaries, or Gulf connections have occurred?
- STQ. 37. How have descriptors of present-day surface and groundwater inflows changed over the period of available data?

2.2.5 Causal Process Questions

1.0. Restore the area, location, species composition, and condition of submerged aquatic vegetation (SAV-- sea grasses, rooted macrophytic algae) to pre-development conditions.

- CPQ. 1. What major activities in the watershed or in the Bay have occurred since pre-development times?

1.1. Bring proximate stressors of SAV (light, turbidity, salinity, exposure, biotic regulators, etc.) into ranges suitable for natural recolonization within areas of SAV extirpation.

CPQ. 2. What are the present-day requirements and limits of healthy SAV for light, turbidity, salinity, nutrients, currents, and exposure?

CPQ. 3. What statistically significant relationships describe the variation of SAV attributes (shoot density, biomass, net production, etc.) as functions of the variation in stressor values?

CPQ. 4. Is physical recruitment a significant factor limiting SAV growth in the Bay? How?

CPQ. 5. Is the growth of epiphytic or drift macroalgae a significant factor in limiting SAV growth in the Bay? How?

1.1.1. Modify quantity and quality of freshwater inflows (surface water, ground water) as needed to relieve proximate stressors, within the context of natural geologic conditions in the Bay.

CPQ. 6. What statistically significant relationships describe the variation of SAV stressors as functions of the variation in values of freshwater inflow quantity and quality?

CPQ. 7. What changes in the quantity or quality of freshwater inflow must be achieved to relieve SAV stressors?

2.0. Create conditions of water quality necessary to increase the area of Estero Bay designated as Class II (shellfish propagation or harvesting) waters of the State, and permit some area of the Bay to be classified "approved" for shellfish consumption.

CPQ. 8. What major activities in the watershed or in the Bay have occurred since pre-development times?

2.1. Bring proximate stressors of shellfish productivity and sanitation (pathogens, turbidity, salinity, exposure, biotic regulators, etc.) into ranges suitable for shellfish propagation and harvesting.

CPQ. 9. What are the present-day requirements of healthy shellfish for turbidity, salinity, exposure, and biotic regulators?

CPQ. 10. What statistically significant relationships describe the variation of shellfish abundance and production as functions of the variation in stressor values?

CPQ. 11. Is physical recruitment a significant factor limiting shellfish abundance and production in the Bay? How?

CPQ. 12. Are predation or parasitism significant factors in limiting shellfish abundance and production in the Bay? How?

CPQ. 13. What are the sources, transport mechanisms, and residence times of pathogens in the Bay?

CPQ. 14. What are the rates of pathogen bioaccumulation and depuration in Bay shellfish?

2.1.1. Modify quantity and quality of freshwater inflows (surface water, ground water) as needed to relieve proximate stressors, within the context of natural geologic conditions in the Bay.

CPQ. 15. What statistically significant relationships describe the variation of shellfish stressors as functions of the variation in values of freshwater inflow quantity and quality?

CPQ. 16. What changes in the quantity or quality of freshwater inflow must be achieved to relieve shellfish stressors?

3.0. Register the location, size, and duration of oligohaline habitat (salinity less than 10 parts per thousand) to pre-development conditions.

CPQ. 17. What major activities in the watershed or in the Bay have occurred since pre-development times?

3.1. Modify quantity and timing of freshwater inflows (surface water, ground water) as needed, within the context of natural geologic conditions in the Bay.

CPQ. 18. What are the present-day requirements of oligohaline habitat for salinity and tidal action?

CPQ. 19. What statistically significant relationships describe the variation in oligohaline habitat location, size, and duration as functions of salinity variation?

CPQ. 20. What statistically significant relationships describe the variation in salinity as a function of the quantity and timing of freshwater inflow?

CPQ. 21. Is sea level rise a significant factor limiting oligohaline habitat in the Bay? How?

2.3 Synthesis

Repetition of questions listed by individual goal invites their consolidation to a manageable number. Status and trend questions can be reduced to 10 questions, and causal process questions can be reduced to 9 questions.

2.3.1 Status and Trend Questions

STQ. 1. What was the pre-development status of valued ecosystem components, in terms of
a. SAV area, location, depth, species composition, and condition,

- b. molluscan shellfish diversity, abundance, and sanitation; and
 - c. oligohaline habitat area, location, species composition, and condition?
- STQ. 2. What changes in valued ecosystem components have occurred from pre-development to modern time, in terms of
 - a. SAV area, location, species composition, and condition,
 - b. molluscan shellfish diversity, abundance, and sanitation; and
 - c. oligohaline habitat area, location, species composition, and condition?
- STQ. 3. What are the geographic and seasonal distributions (and other statistical properties) of measured values for the following stressors regulating valued ecosystem components, *specifically for open Bay waters*:
 - a. water temperature, salinity, light attenuation, color, chlorophyll, mineral and organic turbidity, nutrients, current speed, wave energy, sediment structure and chemistry, and tidal exposure values (for SAV); and
 - b. also pathogen type and abundance, and dissolved oxygen (for shellfish)?
- STQ. 4. How have statistical descriptors of present-day stressors changed over the period of available data, for SAV and shellfish in the Bay?
- STQ. 5. What are the ranges, statistical distributions, and seasonal and spatial variations of present-day fresh water flow to the Bay, in terms of
 - a. direct precipitation,
 - b. gaged surface water discharge via waterways,
 - c. ungaged surface water discharge via waterways,
 - d. sheet flow,
 - e. water table and surficial aquifers,
 - f. confined aquifers; and
 - g. permitted point and non-point source discharges.
- STQ. 6. How have statistical descriptors of present-day fresh water flow changed over the period of available data?
- STQ. 7. What are the geographic and seasonal distributions (and other statistical properties) of measured values for the following stressors regulating valued ecosystem components, *specifically for fresh water flowing to the Bay*?
 - a. water temperature, salinity, light attenuation, color, chlorophyll, mineral and organic turbidity, nutrients, current speed, sediment structure, and oxygen demand values (for SAV); and
 - b. also pathogen type and abundance, and dissolved oxygen (for shellfish)?
- STQ. 8. How have statistical descriptors of present-day SAV and shellfish stressors changed over the period of available data, in fresh waters flowing to the Bay?
- STQ. 9. What are the present-day spatial characteristics of Bay sediments with respect to:
 - a. age, provenance, transport, and deposition,
 - b. thickness, granulometry, and mineral composition,
 - c. organic content and oxygen demand; and
 - d. anthropogenic contaminant concentrations?

STQ. 10. What changes in sediment characteristics have occurred in recent times?

2.3.2 Causal Process Questions

- CPQ. 1. What major physical changes have occurred in the study area, in terms of:
 - a. topography of the watershed; and
 - b. bathymetry of the Bay, its tributaries, or Gulf connections?
- CPQ. 2. What are the present-day seasonal requirements and limits of valued ecosystem components (species diversity, shoot density, biomass, net production, etc. for SAV; diversity, abundance, and sanitation of shellfish; area, location, and species composition of oligohaline habitat), in statistically significant terms of the following stressors:
 - a. freshwater supply and tidal action (for oligohaline habitat),
 - b. water temperature, salinity, light availability, nutrients, current speed, wave energy, sediment structure, and tidal exposure values (for SAV); and
 - c. also pathogen type and abundance, and dissolved oxygen (for shellfish)?
- CPQ. 3. Is physical recruitment a significant factor limiting SAV or shellfish abundance and production in the Bay? How?
- CPQ. 4. Do biological interactions regulate valued ecosystem components more than abiotic stressors, specifically in terms of
 - a. epiphytic or drift macroalgal inhibition of SAV; and
 - b. predatory or parasitic inhibition of molluscan shellfish?
- CPQ. 5. What statistically significant relationships describe the variation of SAV and molluscan shellfish stressors, as functions of the variation in values of freshwater inflow quantity, quality, and timing,
 - a. for stressor values measured in freshwater inflows; and
 - b. for stressor values measured in the Bay?
- CPQ. 6. What changes in the quantity, quality, or timing of freshwater inflow must be achieved to relieve stressors regulating valued ecosystem components?
- CPQ. 7. What are the sources, transport mechanisms, and residence times of pathogens in Bay waters and sediments?
- CPQ. 8. What are the rates of pathogen bioaccumulation and depuration in Bay shellfish?
- CPQ. 9. Is sea level rise a significant factor affecting valued ecosystem components in the Bay, in terms of
 - a. regulating Bay geometry, elevation, sedimentation, or tidal exposure;
 - b. altering circulation, flushing, or salinity in open waters or tributaries; or
 - c. decreasing maximum depths of submerged aquatic vegetation?

2.3.3 Technical Rationale for Research Questions

Research questions frame the types of investigations needed to complete lines of evidence leading *from* valued ecosystem components *to* management decisions and actions affecting fundamental processes such as freshwater inflow, nutrient enrichment, or contaminant loading. Thus, the

underlying rationale for questions posed in this chapter is that each causes particular kinds of data to be produced in order that status and trends of valued ecosystem components may be defined and linked empirically, if not mechanistically, to their immediate stressors and ultimate regulating factors.

For purposes of this research program, Estero Bay's valued ecosystem components were identified in Chapter 1 as submerged aquatic vegetation, shellfish, and oligohaline habitats. Goals identified in Chapter 1 posit the management end-points desired for each VEC. Nineteen questions were identified as both necessary and sufficient to establish the status and trends of each VEC, as well as relate the VECs to their respective ecological stressors. Some of the 19 questions also link the status and trends of ecological stressors to the controlling effects of physical, hydrological, and chemical processes. Technical insights to each question are given below, using submerged aquatic vegetation as an example.

STQ. 1. What was the pre-development status of valued ecosystem components, in terms of... SAV area, location, depth, species composition, and condition?

STQ. 2. What changes in valued ecosystem components have occurred from pre-development to modern time, in terms of... SAV area, location, species composition, and condition?

Areal extent of SAV has a long history of use as a research and management parameter (Leverone *et al.*, 1991). Declines in SAV area are accepted indicators of system decline and, in certain cases, increases are accepted indicators of management success (Tampa Bay National Estuary Program, 1996). Horizontal location of SAV is sometimes used in salinity management programs, but vertical location (i.e., depth distribution) has been used more to address questions relating to submarine light availability (Kenworthy *et al.*, 1990). Species composition has been interpreted in terms of community succession (Williams, 1990). Condition of SAV encompasses a number of parameters, including cover (patchy, sparse, dense, etc.); density (shoot or blade number); luxuriance (canopy height); above- and below-ground biomass; levels of epiphyte cover (Dixon and Kirkpatrick, 1995), and net productivity (carbon fixation) rates. Using methods identified in Chapter 3, it should be possible to establish SAV status and trends for one or more of the listed parameters, for all or part of Estero Bay, or for sentinel beds.

STQ. 3. What are the geographic and seasonal distributions (and other statistical properties) of measured values for the following stressors regulating valued ecosystem components, *specifically for open Bay waters*: water temperature, salinity, light attenuation, color, chlorophyll, mineral and organic turbidity, nutrients, current speed, wave energy, sediment structure, and tidal exposure values (for SAV)...?

- STQ. 4. How have statistical descriptors of present-day stressors changed over the period of available data, for SAV...in the Bay?

(The following rationale applies also to Status and Trends Questions 7 and 8.)

Temperature and salinity exert horizontal and vertical controlling effects on sea grasses (Zieman, 1974). Light attenuation exerts vertical control on seagrass depth distribution (Canbridge and McComb, 1984), but in order to understand the mechanisms responsible for causing attenuation it has been found necessary to account also for nutrients, color, phytoplankton blooms --as chlorophyll, and turbidity (McPherson and Miller, 1987). Turbidity may be organic or inorganic; mineral turbidity refers to "whiting" (*in situ* calcium carbonate precipitation-- Heyl, 1992), suspended sediments (Short and Short, 1984), and certain types of effluents. Attached algae may also attenuate light (Dixon and Kirkpatrick, 1995) but its role is addressed by STQ 1 and 2, and CPQ 4. Currents, waves, and tidal exposures also affect SAV (Strawn, 1961), and in a shallow system such as Estero Bay, must be reckoned as part of the status and trend assessment. Recommended research (Chapter 4) will seek to understand each of these stressors in terms of their average states, ranges, variances, and changes through time.

- STQ. 5. What are the ranges, statistical distributions, and seasonal and spatial variations of present-day fresh water flow to the Bay, in terms of
- direct precipitation,
 - gaged surface water discharge via waterways,
 - ungaged surface water discharge via waterways,
 - sheet flow,
 - water table and surficial aquifers,
 - confined aquifers; and
 - permitted point and non-point source discharges.

- STQ. 6. How have statistical descriptors of present-day fresh water flow changed over the period of available data?

Fresh water flow to Estero Bay is a primary, physical controlling process to which management action can be directed. In order to know what fraction of total flow is represented by manageable flow, an accounting of all sources is needed. These questions address the status and trends of freshwater inflow. Direct precipitation may be significant in light of the Bay's shallow nature. Surface and ground waters reach the Bay by several routes that must be quantified. Recommended research (Chapter 4) will seek to understand each of these routes in terms of their average contributions, ranges, variances, and changes through time. Issues of constituent concentrations and loads are raised by subsequent questions.

- STQ. 9. What are the present-day spatial characteristics of Bay sediments with respect to:
- age, provenance, transport, and deposition,
 - thickness, granulometry, and mineral composition,
 - organic content and oxygen demand; and

- d. anthropogenic contaminant concentrations?
- e. STQ. 10. What changes in sediment characteristics have occurred in recent times?
Although sedimentation and sediment structure are included as SAV stressors in previous questions, separate questions regarding the details of Bay sediments are deemed necessary (see Chapter 1, page 26, for the rationale behind a geological context for research goals and questions.) Sediment age, provenance (place of origin), transport mechanisms and rates, and deposition sites and rates are parameters used in reconstructing a bay's geologic past, and in interpreting its present structure and controlling processes (Davis, 1987). Geologic evidence also provides proxy records of VEC status and trends, and evidence for the range of natural perturbations (floods, storm surges, etc.) affecting the Bay. Sediment thickness, granulometry (size-distribution) and mineral composition provide critical data for assessing the suitability of Bay bottoms as habitat for SAV and shellfish (Orth, 1977). Organic content, oxygen demand, and contaminant concentrations can be used to assess the extent and severity of human influences (Zarbock *et al.*, 1997). Human influences are primary, cultural controlling processes to which management action can be directed.

CPQ. 1. What major physical changes have occurred in the study area, in terms of:

- a. topography of the watershed; and
- b. bathymetry of the Bay, its tributaries, or Gulf connections?

Concerning seagrasses, it is necessary to know the extent to which physical alteration of Bay bottom has been directly responsible for SAV trends. In other Florida bays, most dredging and filling has occurred along the shallow margins of the estuary (Goodwin, 1984), principally in prime SAV habitat. Seagrass restoration strategies elsewhere censor such altered areas in computing SAV recovery potential (Janicki *et al.*, 1994).

CPQ. 2. What are the present-day seasonal requirements and limits of SAV (species diversity, shoot density, biomass, net production, etc.)... in statistically significant terms of... water temperature, salinity, light availability, nutrients, current speed, wave energy, sediment structure, and tidal exposure values...?

This question, with CPQ 5 ("What statistically significant relationships describe the variation of SAV...as functions of the variation in values of freshwater inflow quantity, quality, and timing, for stressor values measured in freshwater inflows and...in the Bay?) establishes the empirical links between VEC, their stressors, and primary controlling factors. By their nature and scope, they sufficiently inform experts in estuarine ecology as to the direction(s) of needed research, including the collateral studies and testing of alternative hypotheses addressed by other questions in this series. Answers to these questions allow CPQ 6 ("What changes in the quantity, quality, or timing of freshwater inflow must be achieved to relieve stressors regulating valued ecosystem components?") to be answered with known levels of

certainty. CPQ 6 also allows for predictions of future conditions to be forecast and evaluated-- the familiar scenario analyses common to water resource modeling.

- CPQ. 3. Is physical recruitment a significant factor limiting SAV...abundance and production in the Bay? How?
- CPQ. 4. Do biological interactions regulate valued ecosystem components more than abiotic stressors, specifically in terms of epiphytic or drift macroalgal inhibition of SAV...?
- CPQ. 9. Is sea level rise a significant factor affecting valued ecosystem components in the Bay, in terms of... decreasing maximum depths of submerged aquatic vegetation?

These questions address collateral issues of importance for Estero Bay's SAV. The Bay's shallow nature, large watershed¹, and large tidal amplitude² suggest that residence times are low (flushing and export are high). Retention of propagules (seeds, asexual sprouts, etc.) may be so low that controlling processes in other estuaries are less important than export in Estero Bay. Broad expanses of level, shallow waters are also conducive to the growth of macroalgae, which can inhibit SAV by light attenuation (Cambridge and McComb, 1984) or blanketing (Cowper, 1978). Low retention and algal inhibition may also compound the effects of a longer light path (caused by sea level rise) to retard SAV at depth.

2.3.4 Assessment

A total of 19 research questions is recommended as the necessary and sufficient study of Estero Bay, relative to previously adopted research goals. Their distribution by goal is illustrated in **Table 1** and their distribution by VEC, salinity, and water quality is depicted in **Table 2**.

The physical and biological controlling processes to which management actions should be directed can be seen from the technical rationale to fall primarily upon freshwater inflows (for all three VEC), followed by nutrient and pathogen loadings (for SAV and shellfish, respectively). What scope exists for meaningful management actions will depend upon three findings of the recommended research.

First, relationships of VEC to stressors, and of stressors to controlling processes, will define the direction and extent of goal-directed changes that can be expected. Within the range of values used to relate dependent and independent variables, management actions may be expected to cause predictable outcomes. Variable ranges have yet to be analyzed and the strength of their co-variance remains to be tested.

¹/ Relative to the surface area of the Bay.

²/ Relative to the Bay's mean depth.

Second, collateral processes such as export of SAV propagules or shellfish predation may be responsible for enduring ecological conditions that limit the scope of VEC response to management actions. Recommended studies will identify the extent of these possibilities.

Third, underlying geological structures, processes, and human alterations may constrain the geographic extent of VEC response to management actions. Knowledge of Estero Bay's geology is central to the design of effective management programs, and recommended investigations will do much to place management options in a useful geological context.

2.4 Discussion

2.4.1 Estero Bay Agency on Bay Management

The Estero Bay Agency on Bay Management (EBABM) has met in subcommittee and as a whole to proffer advice on the Research Plan (Everham, 1998). The Agency's review of Chapter 1, Research Goals, resulted in a series of recommendations which are listed and addressed below, together with an assessment of their consequence for this Chapter.

The EBABM agreed to the following issues as important for consideration for addition to the research goals:

- C Inclusion of fish and wildlife resources and connection to habitat mapping;
- C Use of both fish and benthic invertebrates as measures of water and habitat quality;
- C Inclusion of mud flats and oyster beds as critical habitats in addition to submerged aquatic vegetation;
- C Determination of the occurrence and distribution of toxic sediments in the Bay, and,
- C Consider restoration of inflows from and outflows to associated coastal marine systems, in addition to freshwater flows.

The recommendations do not state expected end-points of management actions, but by the resources and processes they address, do provide useful guidance in the refinement of existing goals, and in the formulation of research questions.

Fish and wildlife resources are addressed by existing goals insofar as three major habitats are used--grassbeds, oyster reefs, and brackish waters. Habitat mapping is a method rather than a goal, and will be included in Chapter 3.

Oysters are benthic invertebrates and their inclusion as part of the shellfish named in a research goal assures that these keystone species will be considered. As used in this report, “shellfish” refers not only to oysters, but also the diverse assemblages of gastropods and bivalves that have commercial or recreational value, or potential value. Consequently, a large and ecologically significant portion of the benthic invertebrate community will be evaluated as part of the existing, planned research.

The Agency intends, however, that other benthic invertebrates, such as the macro-infauna of soft bottom communities, also be considered as measures of water and habitat quality. An advantage of using invertebrates is that state law prohibits reductions in species diversity. A disadvantage is that this criterion has never been used in the context of water management. On balance, it should be possible to include benthic invertebrates as part of the SAV and shellfish communities for which goals have been developed. Research questions cited in this Chapter may also be adapted to consider benthic invertebrates by adding to STQ 9 the line, “*e. benthic infaunal invertebrates.*” This amendment would thus modify the scope of STQ 10, as well.

Oyster beds will be addressed as critical habitat because of the shellfish goal and associated research questions. Mud flats can be accounted for by difference (not SAV and not shellfish bed).

Toxic sediments are accounted for by STQ 9 and 10, and connections to associated coastal marine systems are accounted for explicitly by CPQ 1, 2, and 9, and implicitly by CPQ 6 and 7.

2.4.2 Chapter 3 Preview

Once research questions have been reviewed and refined, each will be used to identify research methods appropriate to Estero Bay. Chapter 3 will contain a review of candidate methods, including segmentation, mapping, and other tools, and identify those most appropriate for each question. Selection of research methods is the penultimate step in developing a research plan, for the methods specify data of particular type. The methods can then be applied to existing data for Estero Bay, and also used in the generation of new data needed to answer the research questions posed in this report.

Table 1. Distribution of recommended research questions by goal. STQ, status and trend question; CPQ, causal process question.

<u>Goal Number</u>	<u>Subject</u>	<u>Research Question Number</u>
1.0.	VEC: submerged aquatic vegetation	STQ 1,2 CPQ 2
1.1.	STRESSORS: abiotic and biotic factors	STQ 3,4,7,8 CPQ 2,3,4,5
1.1.1.	CONTROLLING PROCESSES: fresh water, salinity, nutrients, etc.	STQ 5,6,9,10 CPQ 1,2,5,6,9
2.0.	VEC: shellfish	STQ 1,2 CPQ 2
2.1.	STRESSORS: abiotic and biotic factors	STQ 3,4,7,8 CPQ 2,3,4,5,7
2.1.1.	CONTROLLING PROCESSES: fresh water, salinity, pathogens, etc.	STQ 5,6,9,10 CPQ 2,5,6,8,9
3.0.	VEC: oligohaline habitat	STQ 1,2 CPQ 2
3.1.	CONTROLLING PROCESSES: fresh water, salinity	STQ 5,6,9,10 CPQ 1,2,6,8

Table 2. Distribution of recommended research questions by valued ecosystem component (VEC), salinity, and water quality. SAV, submerged aquatic vegetation; S, shellfish; OH, oligohaline habitat.

<u>Research Question</u>	<u>VEC</u>	<u>Fresh Water</u>	<u>Salinity</u>	<u>Water Quality</u>
STQ 1	SAV,S,OH	no	yes	yes
STQ 2	SAV,S,OH	no	yes	yes
STQ 3	none	no	yes	yes
STQ 4	none	no	yes	yes
STQ 5	none	yes	no	no
STQ 6	no	yes	no	no
STQ 7	no	no	yes	yes
STQ 8	no	no	yes	yes
STQ 9	no	no	no	no
STQ 10	no	no	no	no
CPQ 1	no	no	yes	no
CPQ 2	SAV,S,OH	yes	yes	yes
CPQ 3	SAV,S	no	yes	no
CPQ 4	SAV,S	no	no	no
CPQ 5	SAV,S	yes	yes	yes
CPQ 6	SAV,S,OH	yes	yes	yes
CPQ 7	S	yes	no	yes
CPQ 8	S	no	no	yes
CPQ 9	SAV,S,OH	yes	yes	yes

Note: STQ 9 and 10 concern Bay sediments.